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THE GEOCHEMISTRY AND PETROGENESIS OF BASALTIC ROCKS OF THE CENTRAL PART OF YOLA BASIN, UPPER BENUE TROUGH, NIGERIA

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ABSTRACT

The basaltic rocks occur in the Ngurore-Numan-Kola area of the Yola Basin, and are exposed as plugs along a belt stretching from Kwanar Kuka in the Northwest to Ngurore in the southeast, a distance of about 85km. The plugs were intruded into sedimentary deposits of Bima sandstone and clayey shale. Geochemically, these rocks display alkali basalt composition. They are relatively enriched in incompatible elements and exhibit narrow range of Zr (160-172ppm), Nb (21-30ppm) and Y (21-24ppm) concentrations among other elements. The concentrations of the HFSE and the REE are virtually constant. The chondrite-normalized REE patterns are parallel to subparallel and generally uniform. These geochemical features underline the comagmatic nature of the suite. The incompatible element profiles suggest that most of these elements including Nb, Zr, Ti, Y and the REE have not been affected by metamorphism. Chemical features of the rocks are typical of within-plate basalts and suggest that their melts were derived from a fertile or plume-related mantle source. Such features are typical of anorogenic A1 type suites related to hot spots, mantle plumes or continental rift zones.

KEY WORDS: Basaltic rocks, Benue trough, petrography, volcanic rocks, Nigeria

INTRODUCTION

Basaltic rocks related to volcanic activities of the Tertiary and Quarternary periods have been identified at several locations in the Yola Basin of the Upper Benue Trough. The Yola Basin and the Gongola Basin form the two arms of the Upper Benue Trough (Fig. la). In the north central part of the Yola Basin, the rocks consist essentially of volcanic plugs of various sizes and shapes with their vents irregularly distributed typifying volcanic activities unrelated to any specific control. The petrography and major elements geochemistry of these rocks have been discussed by Ntekim and Adekeye (2003); and beside this, there has been no geochemical information on these rocks in the literature. However, in order to better understand the characteristics of their environment of formation, it is important and necessary to study their petrochemical affinities. To further understand the nature and origins of the rocks of this region, new chemical data for twelve samples collected at Kwanar Kuka, Kola, Hossere Bembel and Ngurore (Fig. 1b), are presented. The aim of this present study is to classify the rocks, deduce the tectonic setting of their formation and propose a model for their origin.

Petrographic Characteristics

The basaltic rocks of the study area have been described by Ntekim and Adekeye (2003). Therefore, only a brief description of their petrographic features will be given. The rocks in this study area which have glomerophyritic textures are dominated by olivine basalts. Plagioclase and olivine form the main phenocrystic phases in these basaltic rocks. The microcrystalline matrix is dominated by plagioclase, olivine, augite and magnetite. The plagioclases, which are generally small-microliths within the matrix or phenocryst phase, form 35-45% of the basaltic rocks. They are often euhedral or subhedral in shape and rarely show zonation. The olivines are the second dominant (25-35%) mineral phase in the basalts. They have euhedral or subhedral crystal shapes. Augite (5-10%) and magnetite (10-15%) are generally observed

in the microcrytalline matrix and rarely occur as euhedral /subhedral phenocrysts together with olivine and plagioclase in the rocks.

TABLE 1: Whole rock chemical analyses of the basaltic rocks of the study area

Element	BE 1	BE 2	BE 3	KW 1	KW 2	KW 3	LA 1	LA 2	LA 3	NG 1	NG 2	NG 3
SiO_2 (%)	53.87	52.20	51.43	51.12	51.71	50.86	50.41	51.38	51.24	50.74	49.71	50.32
$Al_2 O_3$ (%)	15.56	15.25	15.47	15.72	15.28	15.52	15.46	15.54	15.75	15.48	15.76	15.82
MgO (%)	5.01	6.07	6.02	6.99	6.87	5.90	6.34	6.58	6.42	6.82	6.85	6.72
FeO (%)	10.48	10.95	10.62	10.83	11.75	11.22	11.70	11.35	10.99	11.69	11.87	11.50
Na_2O (%)	3.64	3.80	3.66	3.72	3.81	3.77	3.99	3.73	3.82	3.71	3.83	3.89
K_2O (%)	1.26	1.31	1.75	1.28	1.47	1.35	1.47	1.42	1.38	1.23	1.26	1.26
CaO (%)	8.52	8.55	8.61	8.72	8.73	8.70	8.78	8.61	8.58	8.59	8.83	8.76
P_2O_5 (%)	0.73	0.75	0.71	0.75	0.76	0.72	0.93	0.88	0.86	0.88	0.86	0.80
TiO_2 (%)	2.15	2.32	2.30	2.33	1.85	2.15	1.85	1.76	1.83	1.94	1.96	1.88
Cu (ppm)	96.27	99.31	98.58	78.42	85.25	80.46	43.37	45.25	44.73	88.65	92.20	90.38
Pb (ppm)	9.22	9.23	9.18	4.72	5.31	5.21	2.88	3.25	2.94	4.86	4.35	4.53
Sn (ppm)	3.4	3.5	2.86	2.0	2.62	2.45	2.2	3.6	3.2	5.42	5.23	5.32
Ba (ppm)	302.0	311.0	315.0	325.0	337.0	332.0	485.0	490.0	502.0	304.0	321.0	345.0
Ni (ppm)	216.0	215.0	220.0	206.2	211.5	215.0	71.0	80.2	73.5	199.2	203.7	200.4
Zr (ppm)	164.4	165.8	166.0	160.8	165.0	163.2	172.0	160.0	164.0	167.8	170.0	172.0
Li (ppm)	5.32	5.04	4.93	5.24	5.33	5.56	9.12	8.78	8.90	4.56	4.87	4.80
As (ppm)	7.62	8.57	7.74	7.93	8.04	8.12	8.56	8.33	8.42	8.93	7.22	8.47
U (ppm)	1.83	1.95	1.88	1.04	2.13	1.84	1.75	1.63	1.67	1.31	1.53	1.46
Th (ppm)	3.22	3.56	3.37	3.18	3.23	3.46	6.54	6.87	6.72	2.75	3.54	3.42
Sr (ppm)	421.05	423.7	430.2	477.0	440.0	456.3	967.1	952.3	948.2	398.0	420.2	405.7
Rb (ppm)	20.83	22.5	22.8	21.6	22.7	21.8	41.0	38.6	42.9	19.0	21.5	20.8
W (ppm)	200,0	205.2	202.7	100.5	150.6	133.2	0.6	0.8	1.2	130.4	126.3	128.5
V (ppm)	243.0	245.0	244.0	216.0	230.0	225.0	241.2	245.6	250.3	227.0	240.5	235.6
Cr (ppm)	441.0	440.0	432.0	403.0	420.0	415.2	149.0	200.0	172.0	364.0	382.0	373.0
Ta (ppm)	61.1	62.0	60.6	9.3	10.2	10.5	4.8	4.5	4.2	39.0	42.0	44.0
Nb (ppm)	23.4	27.5	26.8	25.3	25.0	26.4	25.2	30.3	25.5	21.5	23.7	21.2
Cs (ppm)	0.3	0.25	0.33	0.40	0.35	0.37	0.62	0.57	0.50	0.35	0.40	0.42

BE – Hossere Bembel, LA – Kola, KWA – Kwanar Kuka, NG - Ngurore

ANALYTICAL TECHNIQUES

Concentrations of the major elements (Table 1) and some trace elements (Table 2) were determined on fused lithium-metaborate discs by X-ray fluorescence spectrometry (Philips PW 1400 spectrometer) at the University of Pittsburgh, using a Rh tube operated at 40KeV and 70mA. Concentrations of Rb, Sr, Zr, Y, Nb, Ga, Pb, U and Th (Table 2) were also determined on pressed pellets by X-ray fluorescence (using a Rh radiation, at 70KeV, and 40mA). The analytical precision is better than 1 percent for most major elements and 5 percent for most trace elements. Concentrations of fourteen rare earth elements (REE) as well as Hf and Ta were determined by ICP-MS. Full details of this method are given in Longerich *et al*. (1990). The chondrite values used for normalization are those of Taylor and McLennan (1985).

GEOLOGIC SETTING:

The Upper Benue Trough of Nigeria is the northernmost portion of the Benue rift structure that extends from the northern limit of the Niger Delta in the South to the southern limit of the Chad Basin in the northeast (Fig la) The geology of the Benue Trough as it relates to its origin and tectonic evolution has been widely discussed and well reviewed by many workers including (Carter *et al*, 1963; Cratchley and Jones, 1965; Burke *et al*.1971; Benkheli, *et al*. 1989; and Guiraud 1989. The Trough has been said to originate as the failed arm of an RRR triple junction (Burke *et al*. 1971) following the

Table 2: Concentration (ppm) of the Rare Earth Elements (REEs) in the basaltic rocks of the Study area

Element	BE 1	BE 2	BE 3	KWA 1	KWA 2	KWA 3	LA 1	LA 2	LA 3	NG 1	NG 2	NG 3
La	30.0	35.0	31.5	32.0	33.0	28.0	41.0	38.0	36.0	39.0	35.0	36.0
Y	21.4	21.8	22.3	24.3	23.5	22.8	23.8	22.7	24.2	22.8	22.6	23.0
Ce	55.4	57.4	56.6	67.6	65.8	66.2	69.3	65.3	67.8	53.6	58.4	55.7
Pr	4.6	4.4	4.8	5.2	6.0	5.5	5.8	5.2	5.5	4.4	4.7	4.8
Nd	19.4	19.3	19.0	21.7	20.8	21.5	25.6	23.2	24.8	18.6	17.9	20.5
Sm	5.7	5.4	5.2	6.3	6.1	6.5	6.9	6.2	6.5	5.4	6.2	5.8
Eu	1.8	1.7	1.9	2.0	1.8	1.6	2.1	2.5	2.3	1.8	2.3	1.9
Gd	5.3	5.2	5.4	5.9	5.3	5.6	6.8	6.5	6.2	5.1	4.9	6.2
Tb	0.8	0.8	0.6	0.9	0.7	1.2	1.0	0.9	1.2	0.7	0.9	1.0
Dy	5.5	5.4	5.2	5.4	4.8	4.9	5.6	5.5	5.2	4.9	4.5	4.8
Ho	0.9	0.8	0.8	0.9	1.0	1.0	0.8	1.2	1.0	0.8	1.2	1.2
Er	2.8	2.6	2.8	3.0	3.2	2.8	3.0	1.5	2.5	2.8	2.4	2.6
Tm	0.3	0.2	0.3	0.3	0.5	0.3	0.4	0.4	0.4	0.3	0.3	0.3
Yb	3.4	3.3	3.6	3.4	3.0	3.0	3.4	3.2	3.2	3.6	3.5	3.6
Lu	0.3	0.3	0.3	0.6	0.5	0.2	0.3	0.6	0.4	0.3	0.4	0.3
Hf	3.3	3.6	3.2	3.4	3.5	3.8	6.9	5.7	6.3	3.4	3.5	4.0

BE = Hossere Bembel, KWA = Kwanar Kuka, LA = Kola, NG = Ngurore

opening of the South Atlantic in the Cretaceous. It is now regarded as having been a tensional feature throughout its history of sedimentation and deformation (Wright, 1989). Based on the presence of certain fold structures, folding in the through is seen as the result of differential block faulting in the underlying basement. The Trough is now envisaged (Wright 1989; Benkhelil *et al*. 1989) as being due to a combination of downwarping and rift-type faulting of an accentuated sialic crust with subsidence enhanced as a result of isostatic loading by the in-filling sediments and overlapping marginal faults. The Cretaceous rocks were subjected to a series of folds which are thought to have resulted from the repeated deformation forces. The main folds consist of series of parallel fold systems conforming roughly with the trend of the Benue Vallay i.e. ENE-WSW with local bends in the E-W direction. There are also some important north-south trending faults in the trough.

The Benue Trough is marked by a lot of igneous activity that is shown by the occurrence of intrusive and extrusive rocks of all forms. The extrusive rocks are thought to have formed from the late Cretaceous to Recent times. They are of typical continental affinity consisting essentially of olivine basalts, trachytes, tholeiitic basalts and phonolites similar to those of the adjoining Jos and Mambilla Plateau regions. Of the over 300 plugs encountered in the Upper Benue Trough, only about 22 are non-basaltic.

The Trough has often been described as being occupied by up to 6000m thick marine and fluviodeltaic sediments that have been compressionally folded in a non orogenic shield environment. In the Yola Basin, the Bima sandstone is found at the base of the sedimentary successions and overlies directly the Basement Complex. It is overlain in the study area largely by alluvium but exposed in the southeast (Fig. 1b).

GEOCHEMISTRY

Major and trace elements contents of the basaltic rocks are shown in Table 1. The rocks are represented by high average values of SiO_2 (51.20), TiO_2 (2.03), FeO (11.25), and low values of Al_2O_3 (15.55), CaO (8.67), MgO (6.55) and K_2O (1.37) wt percent respectively. Total alkali (Na_2O+K_2O) content ranges between 4.90 and 5.46 wt percent showing the alkaline nature of the rocks. SiO_2 exhibits narrow range of variation (49.71-53.87) and the concentration is still representative of the protolith and reflects its basaltic nature. The average CaO concentration in the basaltic rocks is comparable to the average CaO

concentration (8.67 wt percent) in typical unaltered basalt (9.66 wt percent) (Cox *et al*. 1979; Le Maitre, 1976).

The concentrations of the rare earth elements (REE) of the analyzed samples are given in Table 2. Large ion lithophile (LIL) and High Field Strength (HFS) elements of the basaltic rocks are represented by high values of Sr (398-967 ppm), Rb (21-43ppm), Ba (303-502ppm), Zr (161-172ppm) and Nb (23-30ppm). Pb, Zr and Nb exhibit narrow ranges of concentration. This feature is in good agreement with other Continental Rift Zone (CRZ) volcanics in the East African Rift Zone (Weaver *et al*. 1972; Lippard 1973) and Southern Turkey (Parlak *et al*, 1998).

Plot of the trace element ratios (Zr/Ti Vs Nb/Y) show the basaltic rocks of the study area to be alkali basalts (Winchester and Floyd 1977) as shown in Fig 2. The presence in appreciable amounts, of olivine classify the rocks as alkali olivine basalts (Irvine and Baragar, 1971; Miyashiro, 1978). Chondrite normalized REE patterns of the alkali basalts (Fig 3) exhibit profiles that are relatively smooth and parallel to subparallel.

TECTONIC SETTING

Major and trace element geochemistry of basalts from different tectonic environments has been examined by many researchers and a diverse collection of discriminant diagrams has evolved. Most of these are based on relatively immobile trace elements such as Ti, Cr, Zr, Nb, Y, Ta and Th (Pearce and Cann 1973; Floyd and Winchester, 1975, 1978; Miyashiro and Fumiko, 1975; Garcia, 1978; Pearce and Norry, 1979). These incompatible elements are considered to be immobile during alteration processes and can be used to characterize petrological affinities and tectonic settings of volcanic rocks (Hart, 1970. Thompson, 1974; Wood, 1980; Meschede, 1986). Also, these elements are most likely to be transported by melts and other fluids passing through the mantle and therefore are likely to preserve evidence of mantle enrichment and depletion processes in their relative abundance (Jakes and White, 1972; Thompson, 1974; Hanson, 1980). Therefore, these elements have been employed in discrimination diagrams to deduce the tectonic setting of the basaltic rocks.

The basaltic rocks of the study area are characterized by LREE enrichment, no EU anomaly and Eu/Sm of 0.32, which according to Cullers and Graf (1984) and Wilson (1989) all indicate the characteristic features of volcanism within the Continental Rift Zone (CRZ). Also, their alkaline nature and enrichment in large ion lithophile (LIL) elements which are features characteristic of Continental Rift Zone magmas suggest that the magma was derived from an enriched mantle source (Bailey, 1983).

Standard tectonic discrimination diagrams Ti/Y versus Nb/Y; Zr/Y versus Zr; Ti-Zr-Y; Nb-Zr-Y; Hf-Th-Ta and Nb-Y-Ce were used to deduce the tectonic setting of the basalts. Using the discrimination diagrams of Pearce and Norry (1979) to assess Ti/Y (Fig. 4) and Zr/Y versus Zr (Fig. 5), the rocks plot in the within-plate fields. In the Ti-Zr-Y diagram of Pearce and Cann (1973), Fig 6, Nb-Zr-Y diagram of Meschede (1986), Fig. 7 and Hf-Th-Ta diagram of Wood (1980), Fig. 8, the rocks plot in the within-plate, within-plate alkali basalts and within-plate basalts and differentiates respectively.

DISCUSSION

Using standard tectonic discrimination diagrams, the Yola Basin basalts with their chemical traits characteristic of “within plate basalts” consistently reflect an anorogenic setting (Figs 4-8). The samples plot in the field of within plate complexes as is typical of A-type suites from other regions worldwide (Collins *et al*. 1983; Whalen *et al*. 1987; Abdel – Rahman and Martin, 1990b; Eby, 1992). The anorogemic geochemical affinities of the rocks are consistent with its inferred geological setting at the Continental Rifted Zone.

The rocks consist essentially of olivine basalts of alkalic affinity and represent within plate lavas. They exhibit relatively high concentrations of Ti, K, Zr, and REE (strong LREE enrichment over HREE). For such rocks, these geochemical characteristics suggest a trace element-enriched source (O1B-like source for

the rocks) and an estimated depth of melt segregation of 70-100Km (Coish and Sinton, 1992; Badger, 1994; Abdel-Fattah and Kumarapeli, 1999).

Bonin (1990) recognized the distinctive nature of A-type magmas and subdivided them into two groups: post-orogenic and early anorogenic. Eby (1990 1992) further subdivided the A-type felsic and intermediate magmas into two groups: A1 which represents differentiates of mantle-derived basaltic magmas (anorogenic or rift zone magmas) and A2 which represents crustal-derived magmas of a post-orogenic setting.

In the diagram designed to discriminate between A1 and A2 groups of anorogenic magmas these rocks belong to the A1 group (Fig. 9) representing within-plate basalts typically related to hotspots, plumes or continental rift zones (Eby, 1992). Also Eby (1990; 1992) found the mafic precursor of Tibbit Hill rocks to be similar to that of ocean island basalts (OIB) which was originally derived from a mantle source. It should be noted that the trace element characteristics of OIBs are generally similar to those of continental anorogenic basalts, and together they constitute within plate basalts (Pearce and Cann 1973).Thus, the basalts are mantle-derived and rift related.

Volcanism in this region has been attributed to a failed arm of an RRR triple junction (Burke and Dewey, 1973; Dewey and Burke, 1974). Evidence in support of this hypothesis is the well-defined rift zone (Benue Trough) which is interpreted as the failed arm. The volcanism occurred at one of the several key lithospheric ruptures that linked to initiate continental breakup. Burke and Dewey (1973) porposed that the Benue Through formed over a rising mantle plume and that the earliest magmatism related to this plume was the emplacement of continental flood basalts. Continued plume activity is indicated by the emplacement of several surrounding alkali complexes. The volcanism appears to have been a relatively short-lived event that took place during some (5.0-4.9) ± 0.2 myr ago after the first of plume-related magmatism that gave rise to the basalts. The volcanism is thus the youngest and extension-related volcanism known from the Continental Rift Zone formed during a rapid phase of rifting and crustal stretching. Based on the plume models of White and McKenzie (1989) and Campbell and Griffiths (1990), Kumarapeli (1993) proposed that the alkaline basaltic magma of Continental Rift Zone form from the hotter mantle at the plume axis beneath attenuated continental lithosphere. Analysis of the geochemical data shows that the basalts geochemically resemble a fertile or plume-related MORB (PMORB) Fig, 10. Compared to basalts derived from a depleted transitional or normal MORB (TMORB or N-MORB), following Menzies and Kyle (1990), they exhibit relatively higher concentrations of Zr and Nb but lower concentrations of Y than basalts characteristic of T-MORB or N-MORB. Similar conclusions were reached by Coish *et al* (1985) and Pinston (1986) from the studies of their respective areas. Thus a plume- source origin is well supported by the geochemistry of the basalts.

The general enrichment of HFS elements in the basalts along with their relatively high La/Yb (8.8-12.0) ratios suggests that these rocks were derived from a fertile, mantle source. Although melting modeling for REE was not performed on these rocks, earlier works by Abdel-Rahman and Martin (1990a) on similar types of rocks indicate that the basalts were generated by partial melting of a primitive mantle source. Also, only a small degree of partial melting of a primitive source was suggested to be required to generate the basaltic magma. As demonstrated by McKenzie and O'Nions (1991) and Lassiter *et al.* (1995), results of REE modeling have placed some constraints on the approximate depth of melting and magma formation. These authors placed magma formation at 80-100km within hot mantle plumes.

The normalized patterns of most of the incompatible elements and REE plotted fall within a consistently narrow range and are smooth and parallel to subparallel. The incompatible element profiles suggest that most of the elements have remained intact and unaffected by any metamorphic event. It should also be noted that relatively smooth normalized patterns are commonly characteristic of unaltered or fresh basalts (Sun *et al*, 1979; Sun, 1980). Pearce and Cann (1973) have noted that the trace element characteristics of OIBs are generally similar to those of continental anorogenic basalts together with which they constitute within plate basalts. Thus the incompatible elements are hereby used to assess the petrological character of

the protolith. The normalized patterns of the REE of the study area are similar to those of OIB and different from those of N-MORB or T- MORB, (Parlak *et al.* 1998).

Based on the study of Mckenzie and O'Nions (1991), Ellam (1992) investigated the relationship between trace element compositions of basalts, variations in thickness of the lithosphere and final depths of melt segregation. Thus Ellam (1992) formulated a method, using REE ratios such as Ce/Yb to estimate depths of extraction of final melts produced at depths shallower than 125km near the lithosphere-asthernosphere interface. Since such ratios are sensitive indicators of changing lithospheric thickness, they will not be radically affected by fractional crystallization. Based on Ellam's (1992) formula, the Ce/Yb average ratio of 20.8 of the Yola basin basalts translates to a final basaltic melt segregation depth of 80km. This interpretation is consistent with the composition of the REE in basaltic rocks (LREE enrichment over HREE).

CONCLUSIONS

The volcamic rocks of the Yola basin have been studied in details and the following conclusions can be made:

1. The basaltic rocks in the study area are represented by alkali olivine basalts.
2. Major and trace elements as well as REE geochemistry of these basaltic rocks are thos of within-plate alkali basalts (WPA) suggesting an enriched mantle source possibly derived from the asthenosphere.
3. Besides being alkaline, the rocks are also enriched in incompatible elements. The profiles of the incompatible elements suggest that most of these elements and the REE have not been affected by any metamorphic event as they have remained largely intact within the basalts.
4. The chondrite normalized patterns of the incompatible elements are parallel to subparallel and generally uniform. These geochemical features underline their comagmatic nature.
5. On the tectonic discrimination diagrams, the rocks display geochemical characteristics of within-plate lavas. This is consistent with the regional geological context in which the volcanism, associated with the RRR triple junction occurred shortly before the onset of sea-floor spreading.
6. Chemical characteristics of the basaltic rocks show that they belong to the A1 group of anorogenic magmas which are related to hotspots, plumes or continental rift-zones indicating that their melts were derived from a fertile or plume-related mantle source.

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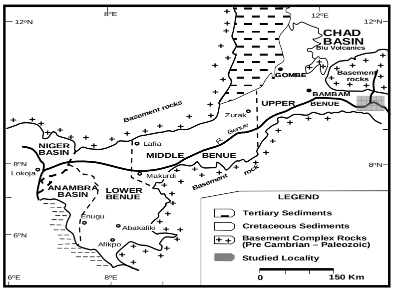

Fig. 1a: Generalised Geological map of the Benue Trough

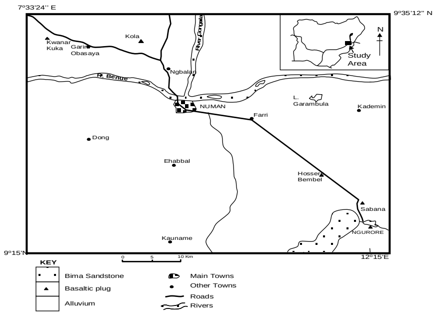

Fig. 1b: Geological map of the study area

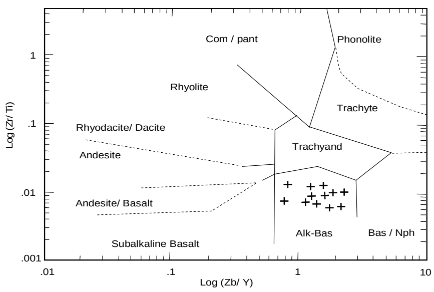

Fig.2: Plot of Zr/Ti versus Nb/Y (after Winchester and Floyd, 1977) showing the type of basaltic rocks of North Central part of Yola Basin.

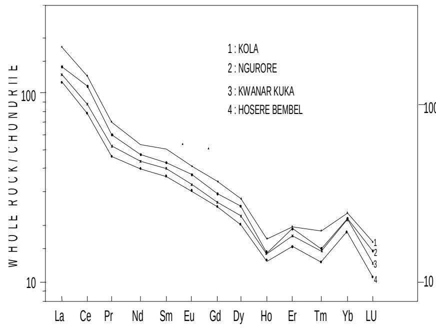

Fig. 3: Chondrite- normalized incompatible

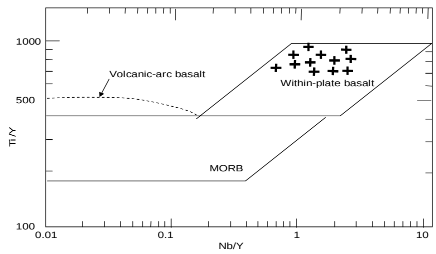

Fig. 4: North Central part of Yola Basin basaltic rocks plotted on the Ti/Y - Nb/Y discrimination diagram of Pearce and Norry (1979).

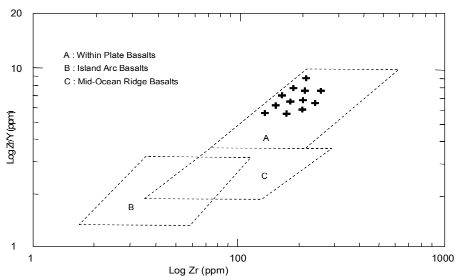

Fig. 5: Zr/Y versus Zr discrimination diagram (after Pearce and Norry, 1979) showing the within plate tectonic environment of the basaltic r

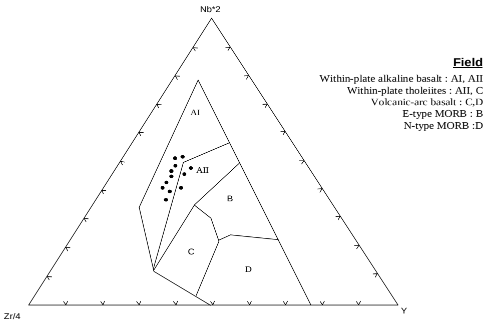

Fig. 6: Ti-Zr-Y discrimination diagram of the basaltic rocks (after Pearce and Cann, 1973).

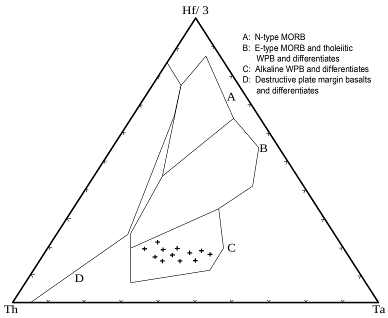

Fig. 7: The basaltic rocks plotted on the Nb-Zr-Y discrimination diagram of Meschede (1986). Ti, Zr and Y concentrations used are in ppm, multiplied or divided as indicated, recast to 100% and plotted based on proportions of respective components.

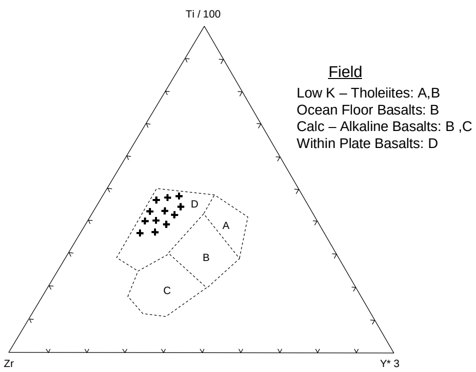

Fig. 8: Hf-Th-Ta discrimination diagram (after Wood, 1980) for the basaltic rocks indicating the tectonic environment.

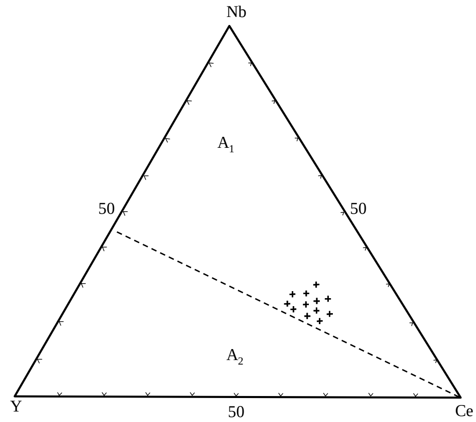

Fig. 9: Nb-Y-Ce discrimination diagram (after Eby, 1990,!992) for the basaltic rocks. Field A1represents a plume-related basaltic source with an anorogenic setting and field A2 represents crustal-derived magmas of posit-orogenic settings.

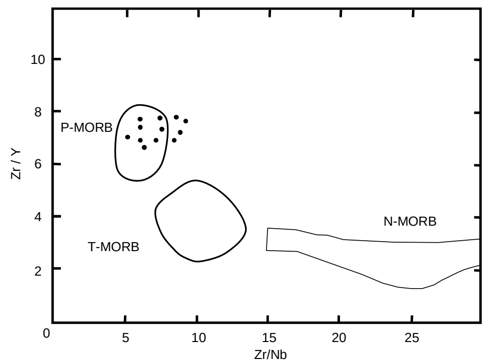

Fig. 10: Zr/Y versus Zr/Nb diagram showing that the basaltic rocks plot in or near the field of fertile related MORB (P-MORB). The other fields are transitional MORB(T-MORB) and normal MORB (N-MORB) and are modified after Menzies and Kyle (1990)

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